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DYNAMICS OF DEPLOYMENT MECHANISM FOR 1 METER RESOLUTION SPACE TELESCOPE

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ABSTRACT

Deployable telescope remain in stowed position in payload fairing of launch vehicle and deployed in orbit to its final form. Development of deployment mechanism is carried out to achieve 100 micron accuracy in separation. Dynamic analysis of Deployment Mechanism is carried out to estimate desired value of stiffness of torsion spring for complete deployment and damping factor of damper to avoid shock at the end of deployment. Actual two link rigid model and flexible model are prepared using MSC ADAMS tool. Dynamic analysis is carried out to estimate Deployment time, joint angle and angular acceleration for link-1 and link-2.

KEYWORDS: Deployment, Telescope, Mechanism, Dynamic Analysis & Damping Factor

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Original Article

1. INTRODUCTION

Telescopes are widely used for space based remote sensing applications. As resolution of telescope increases, the size of telescope increases. But there is limitation on size of telescope in payload fairing of launch vehicle. Deployment mechanism for telescope satisfies this need. A deployment mechanism for a 1m resolution space based telescope is being developed under a Technology Development Program (TDP) at Space Applications Center, ISRO.

An initial concept demonstration model of mechanism was developed as shown in Figure 1. The deployment Mechanism (DM) of phase-1 has three legs, each consist of following elements: revolute joint, rigid link having round c/s, two side two point latch mechanism and torsion spring as an actuator. The separation characterization is carried out for DM phase-1 and deployment accuracy in separation is foud out to be 500 micron.

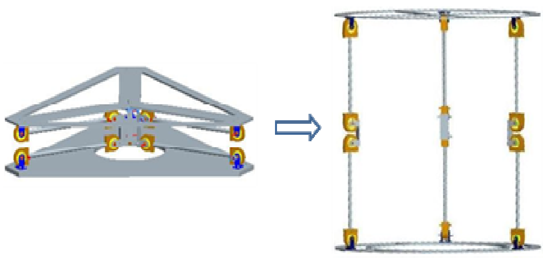

Figure 1: Deployment Mechanism: Phase 1.

Phase 2 of the project is aimed at developing a mechanism for 100 micron deployment accuracy in separation. This model has a single link in the mechanism in order to reduce the number of joints and related

complexities. Modificatons exists in the design of latch mechanism, joint and link. The mechanism consists of a primary link, secondary link, joints, actuator-damper, latch mechanism. The deployment mechanism in stowed and deployed condition is shown in Figure 2. The scope of the present work is related to Phase 2 of the project.

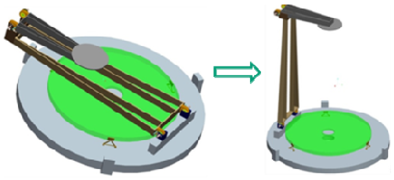

Figure 2: Deployment Mechanism: Phase 2.

The deployment dynamics and related activities of deployment mechanism are discussed in this paper. The mechanism is deployed in orbit with the help of actuator like spring. The latch mechanism is used for locking of deployment mechanism in intended position to achieve desired separation and alignment accuracy. The locking induces large latch up load at hinges and mechanism interfaces. A damper is used to reduce latch up loads. The desired value of the stiffness of spring for complete deployment and damping rate required to minimize the shock during latching to the specified value will be estimated.

The work presented here in this paper includes dynamics of single link and two-link model, actual two link rigid model and two link flexible model. Dynamic analysis is done before and after damping to find joint angle, deployment time and acceleration for link-1 and link-2.

2. DYNAMICS OF SINGLE LINK MODEL

Schematic representation of single link model is as shown in Figure 3. Assembly is made with rigid link, revolute joint and spring-damper unit. The motion of link is described in Figure 3. Initially link is at zero position and gets deployed to final angle of 90 degree. Link is actuated by means of a pre-loaded torsion spring. When link attains final deployed position, then it get locked and remain in same position because of torsion spring pre-load.

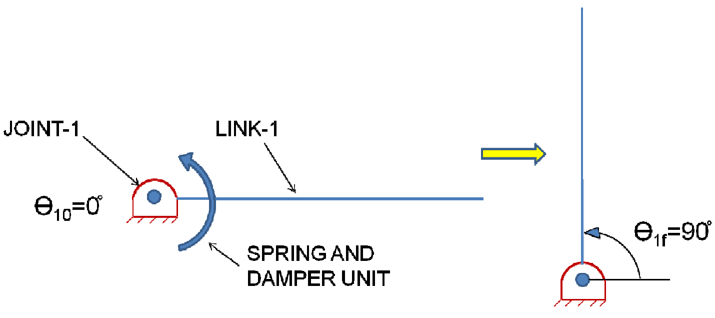

Figure 3: Mathematical Model of Single Link Model.

2.1 Mathematical Modelling

Mathematical model is developed for single link model using Lagrangian formulation. For single link model, general solution is derived for critically damped system [Equation (1)] and for under damped system [Equation (2)]. Results of mathematical model and MSC ADAMS model for single link model are validated.

$$\theta(t) = (\theta_0 + (\dot{\theta}_0 + \omega\theta_0).t)e^{-\omega t} \quad (1)$$

$$\theta(t) = e^{-\epsilon\omega t}\left\{\theta_0.\cos\sqrt{1-\epsilon^2}.\omega.t + \frac{(\dot{\theta}_0 + \epsilon\omega\theta_0)}{\sqrt{1-\epsilon^2}.\omega}.\sin\sqrt{1-\epsilon^2}\omega t\right\} \quad (2)$$

2.2 MSC ADAMS Model

Single link model in MSC ADAMS tool is shown in Figure 4. Revolute joint is defined at the end of link so that it imparts single degree of freedom to the system. Link is fixed to the ground using fixed joint. Spring-damper unit is defined at the same marker at which revolute joint is defined. Link size is 500X50X25 mm. Material assigned to the link is AL6061-T6. Torsion spring has given a pre-load of 90˚, so that link gets deployed from 0˚ angle to final position of 90˚. Measure is defined at the torsion spring marker to measure joint angle.

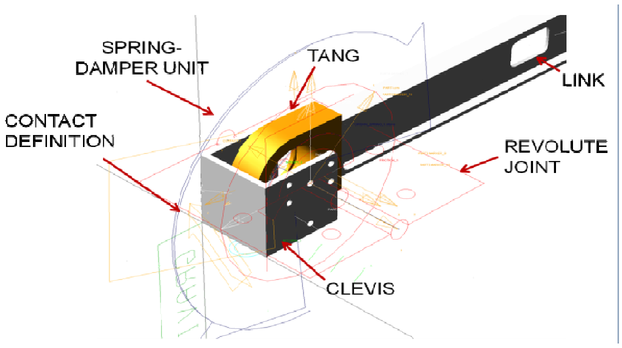

Figure 4: MSC ADAMS Model of Single Link Model.

2.3 Results Validation

Input parameters for single link model for result validation using mathematical modeling and MSC ADAMS results are given below:

- Torsion Spring Stiffness (K) = 3.57 N-m/deg =204.5461056 N-m/rad.
- Inertia of link about rotation axis (I) = 0.457 kg-m^2
- Critical damping value (C_c) = 2.√(K.I) = 2.554596 Nm-Sec/deg
- Damping value for under damped system (C)= 0.1 Nm-Sec/deg
- Pre-load to torsion spring = 90˚
- Boundary conditions: At t=0, θ= -90˚ and at t=0, $\dot{\theta}$=0˚.
- Deployment time = 10 Seconds

In MSC ADAMS after defining all the input parameters to the single link model simulation are done for deployment of single link model. Each simulation runs for 10 seconds. Inertia of link in MSC ADAMS is checked with the Pro-E model of link about axis of rotation and then it is used for result validation.

Results obtained from above activity are shown in Figure 5. Angle Vs time plot is obtained for both the cases that are critically damped and under damped system solving mathematical model and simulation in MSC ADAMS. Results are closely matching.

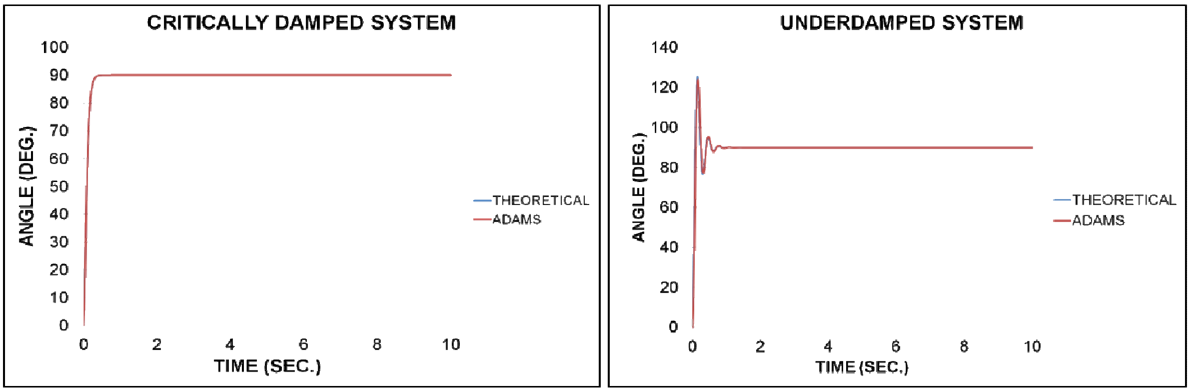

Figure 5: Results Validation for Single Link Model.

3. DYNAMICS OF TWO LINK MODEL

Schematic representation of two link model is as shown in Figure 6. There are two links link-1 and link-2, which are interfaced with a revolute joint and link-1 is interfaced with fixed link through revolute joint. At each joint, there is spring damper unit for deployment of two link model. Initial angle that is in stowed condition of link-1 is 0˚ and gets deployed to final angle of 90˚. The angle of link-2 is considered with respect to link-1. The initial angle for link-2 is 180˚ and deployed to final angle of 270˚. Preload is given to the torsion spring as for link-1 it is 90˚ and link-2 it is 270˚. The two links remain in final intended position with the help of torsion spring preload and locking.

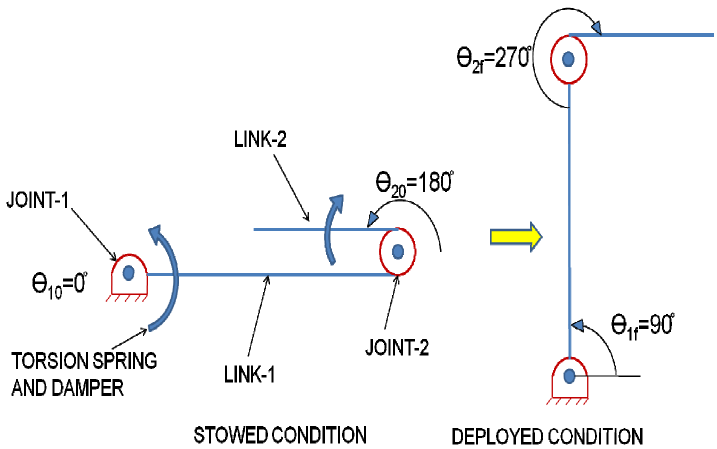

Figure 6: Mathematical model of two link model.

3.1 Mathematical Modeling

Mathematical model is developed for two link model using Lagrangian formulation. Equations (3) and (4) are second order, coupled, simultaneous differential equations. These equations are solved using Runge Kutta method using STATE SPACE format. Mathematical model results are validated with MSC ADAMS model.

$$(I_1.\ddot{\theta}_1) + [(C_1 + C_2).\dot{\theta}_1 - C_2\dot{\theta}_2] + [(K_1 + K_2).\theta_1 - K_2\theta_2)] = 0 \qquad (3)$$

$$(I_2.\ddot{\theta}_2) + [-C_2\dot{\theta}_1 + C_2\dot{\theta}_2] + [-K_2\theta_1 + K_2\theta_2)] = 0 \qquad (4)$$

3.2 MSC ADAMS Model

Two-link model is modeled using MSC ADAMS tool. Figure 4 shows joint, spring, damper for the link-1 and same

interfaces are present for the link-2 and its corresponding spring, damper and joint. Marker is created at the rotation axis of link-1 and similarly for link-2. Joint, spring and damper is defined at the same marker for link-1 and link-2. Fixed joints are used for fixing the mechanism to the ground. AL6061-T6 material is assigned to link-1 and link-2. Inertia of link-1 and link-2 are calculated using PRO-E tool and validate with obtained inertia from MSC ADAMS model. Here, two measures are define at markers of torsion spring-1 and torsion spring-2. Those measures are used to obtain joint angle Vs time plot for link-1 and link-2.

3.3 Result Validation

Considering same input parameters for the mathematical model and MSC ADAMS model of two link deployment mechanism, then results are compared. Input parameters are given below:

- K_1=stiffness of torsion spring-1= 3.57 Nm/deg = 204.5194144 Nm/rad
- K_2=stiffness of torsion spring-2= 3.57 Nm/deg = 204.5194144 Nm/rad
- C_1=damping coefficient of damper-1= 3.491111 Nm-Sec/deg = 200 Nm-sec/rad
- C_2=damping coefficient of damper-2 = 2.61833 Nm-Sec/deg = 150 Nm-sec/rad
- I_1=inertia of link-1 about rotation axis = 0.1498596 kg.m^2
- I_2=inertia of link-2 about rotation axis = 0.0231 kg.m^2
- Θ_{10}=initial angle of link-1= 0˚
- Θ_{20}=Initial angle of link-2 = 180˚
- Preload for torsion spring-1= 90˚
- Preload for torsion spring-2= 270˚

In MSC ADAMS after modelling of system simulation is run for 20 seconds. The results are verified for under damped, critically damped and over damped system of two link model. Here, results are shown for over damped system. Validation results of two link model using mathematical modeling and MSC ADAMS model are as shown in Figure 7.

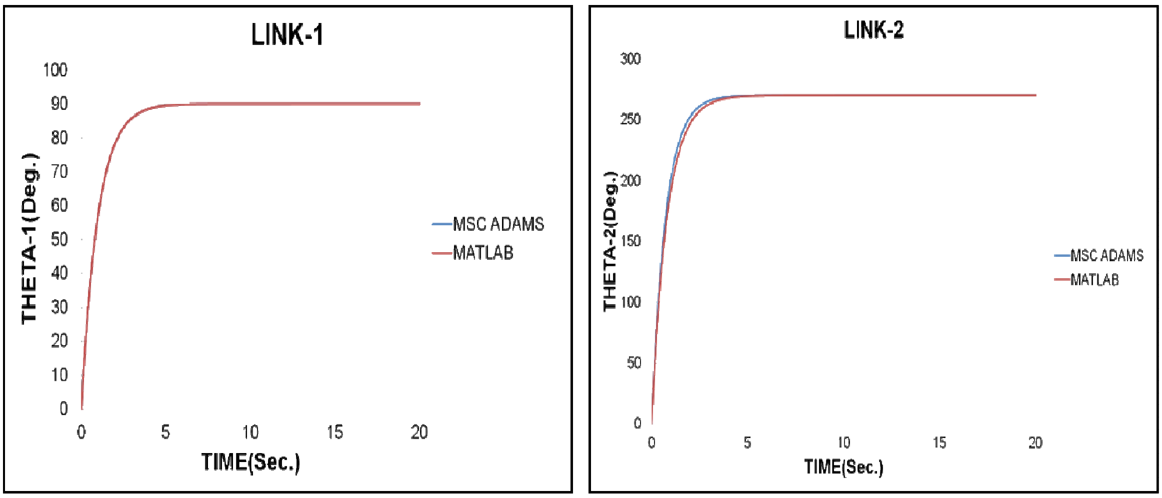

Figure 7: Results Validation for Two Link Model using MSC ADAMS and Mathematical Model.

4. DYNAMICS OF ACTUAL TWO LINK RIGID MODEL

Actual two link rigid model of deployment mechanism for telescope is modeled using MSC ADAMS tool as shown in Figure 8 Joints, spring-damper unit and locking are exactly simulated in MSC ADAMS model. Elements of actual two link model of deployment mechanism are as shown in figure 8

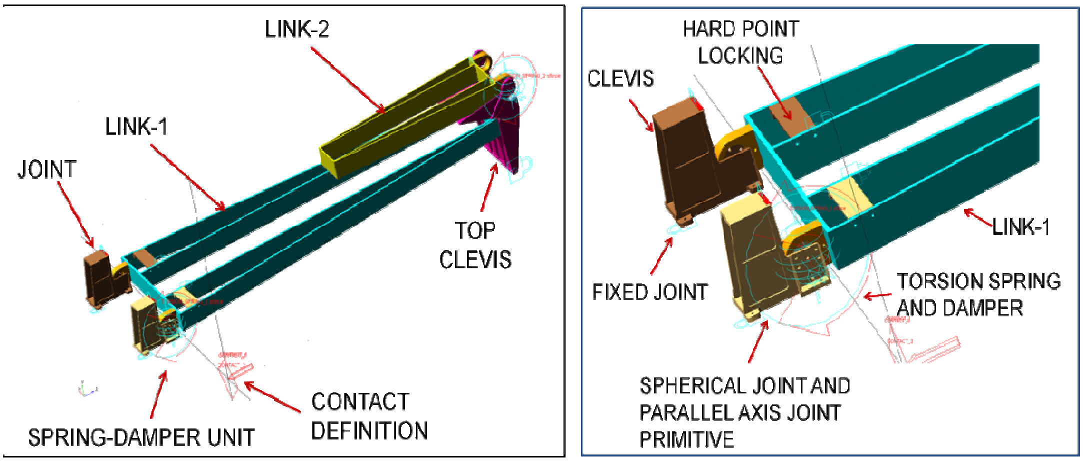

Figure 8: Two Link Rigid Model in MSC ADAMS.

All the rigid bodies are interfaced with each other using joints. Clevises are interfaced with ground through fixed joint so that they are fixed to ground during simulation. Fixed joints are defined at all interfaces where there is no relative motion in between them. Revolute joints are defined in between tang and clevis (left, right and top). Gravity is defined as zero as this activity is exactly simulated for space application. Material is assigned to all parts of deployment mechanism. Torsion spring and damper is defined at the same marker at which revolute joints are defined.

Mechanism is checked for constraint redundancy and it is observed that equations of motions are not able to solve because two revolute joints are defined at same rotation axis. To avoid this redundancy in constraint one spherical joint and one parallel axis joint primitive is defined. The spherical joint locks 3 DOF in translation and parallel axes joint primitive locks 2 DOF in rotation. There are two spherical and to parallel axes joint primitive in actual two link model of deployment mechanism as DOF of mechanism is two.

Two variables are defined in MSC ADAMS model (MSC ADAMS/ Design variable/ new...) one for damping coefficient and other for stiffness of spring. These variables are used for selection of stiffness and damping value. Initially no damping is defined and simulation is run for certain time duration. Then variable is defined at torsion spring definition for stiffness. Measures for link-1 and link-2 are defined at the torsion spring to measure its angular displacement.

4.1 Selection of Torsional Stiffness of Spring:

Design evaluation is carried out to study effect of varying stiffness value on joint angle. After number of iterations and by the bi-section method, it is observed that damping value lie in between 0.005-0.03Nm/Deg. So design study is carried out for the varying stiffness value from 0.005-0.03 Nm/Deg. For the design study measure is maximum value of joint angle of link-1. For certain value of torsional stiffness value of maximum joint angle-1 will be close to the 90˚. That value of torsional stiffness is selected as estimated value for further analysis. Figure 9 shows results obtained for the above design study.

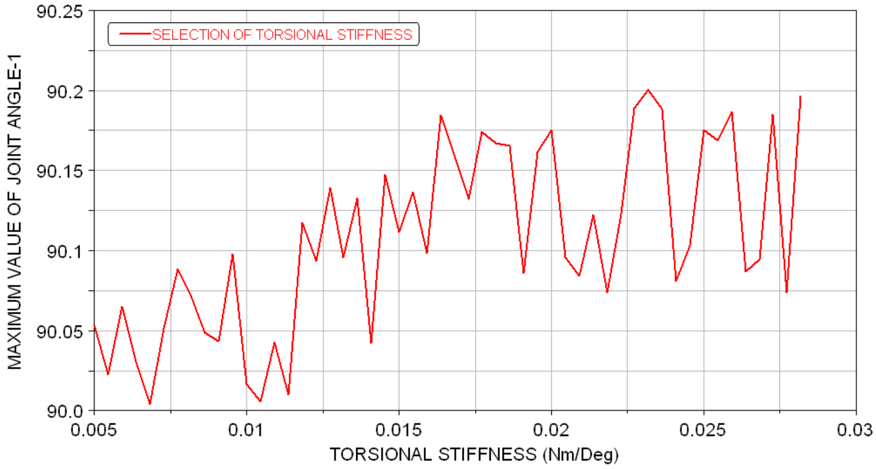

Figure 9: Selection of Torsional Stiffness of Spring.

4.2 Selection of Damping Coefficient for Damper

Design variable is created for damping coefficient. Damping value is now defined for torsion spring definition in MSC ADAMS tool. Design study is carried out to study effect of change in torsional damping value on maximum value of joint angle of link-1. Measure is defined for design study such as maximum value of deformation for torsion spring. It is observed by interpolation and BI-section method that damping value is lies within 5E-04 to 0.001 Nm.Sec/Deg. Variable is defined as maximum and minimum value for the above range of damping. Then, results are obtained for maximum value of joint angle-1 vs torsional damping value. Results are as shown in Figure 10. Torsional damping value is selected for which joint angle-1 is close to 90˚.

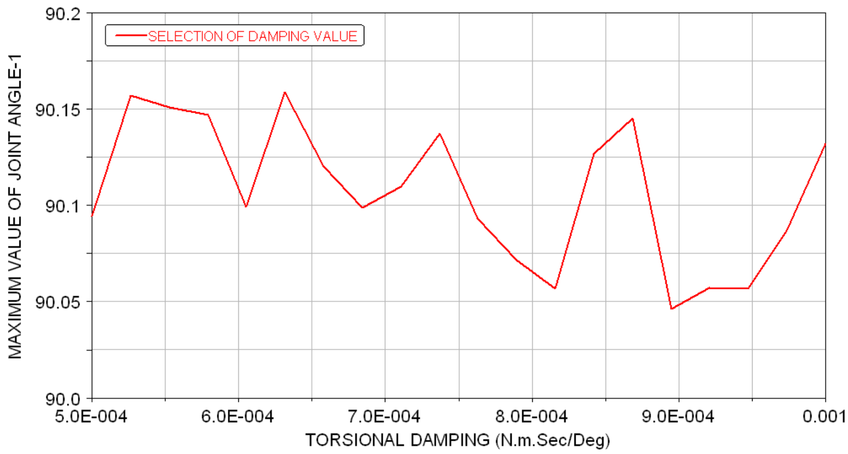

Figure 10: Selection of Damping Coefficient for Damper.

Above design study is carried out for link-1 and it measures joint angle-1. Similarly, it is carried out for link-2 and it measures joint angle-2. From number of iterations for two-link model before and after damping and then results are converged for stiffness and damping value for torsion spring of link-1 and link-2. Values of stiffness and damping coefficient are given below:

- Stiffness Torsion spring-1 for joint-1= 0.01Nm/deg
- Stiffness Torsion spring-2 for joint-2= 5E-04 Nm/deg

- Damping coefficient for joint-1= 0.09 Nm.sec/deg
- Damping coefficient for joint-2= 2E-03 Nm.sec/deg

4.3 Deployment Mechanism simulations in MSC ADAMS before and after damping for two link rigid model:

Estimated value of torsion spring stiffness and damping coefficient were defined at joint-1 and joint-2. Simulation study is carried for two link rigid model for 20 seconds. Simulation study was done before and after damping. Measures are defined at joint-1 to measure joint angle-1, at joint-2 to measure joint angle-2 and C. M. angular acceleration of primary link. Results are given below:

Joint angle-1 vs time graph for before and after damping is shown in Figure 11. From this graph, it is observed that link-1 achieve its final position i.e. 90 deg in 6 seconds before damping and 90 deg in 8.4 seconds after damping.

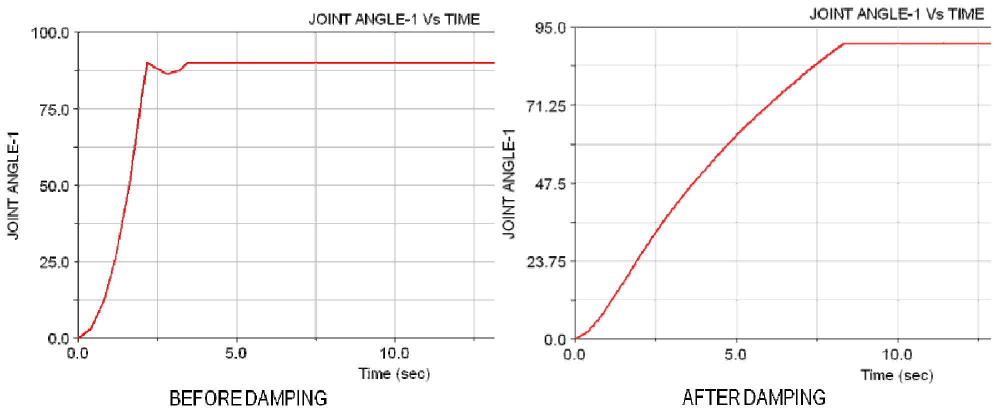

Figure 11: Joint Angle-1 Vs Time (Before and after Damping).

Joint angle-2 vs time graph for before and after damping is shown in Figure 12. From this graph, it is observed that link-1 achieve its final position i.e. 270 deg in 5.5534 seconds before damping and 270 deg in 10 seconds after damping.

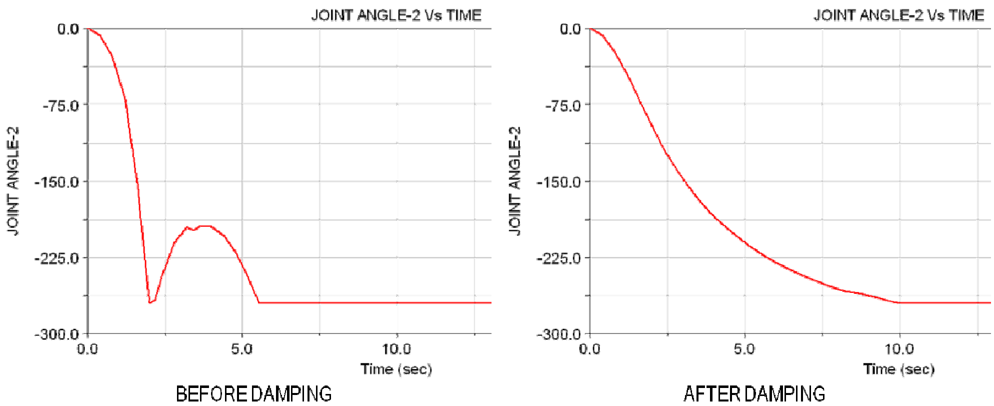

Figure 12: Joint Angle-2 Vs Time (Before and after Damping).

Angular acceleration vs time graph for before and after damping is shown in Figure 13. From this graph, it is observed that angular acceleration is 6928.82 deg/sec^2 before damping and 338.729 deg/sec^2 after damping. It was observed that shock forces at the end of deployment will be minimized because of damping.

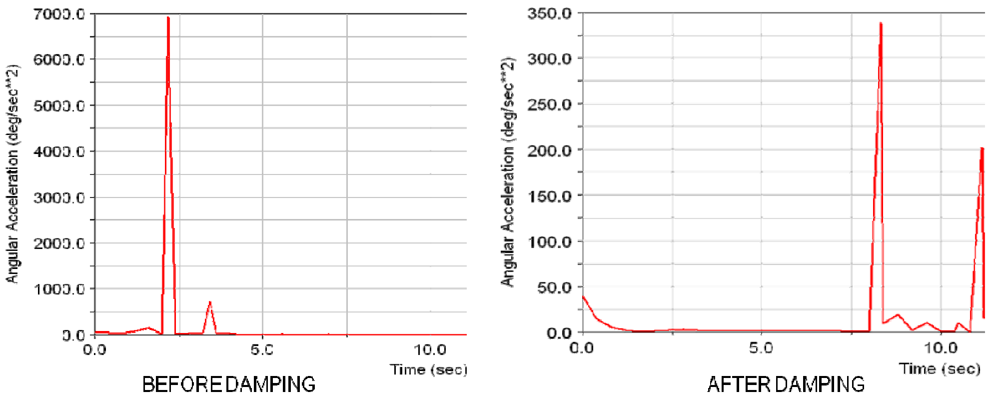

Figure 13: Angular Acceleration Vs Time (Before and after Damping).

5. DYNAMICS OF ACTUAL TWO LINK FLEXIBLE MODEL

Rigid model is the initialization of study of dynamics of deployment mechanism. Considering link as flexible link tends to realistic dynamic analysis of deployment mechanism. Using this, one can easily study effect of spring stiffness and damping coefficient on joint angle for link-1 and link-2, deployment time, angular acceleration.

Joints definition, spring definition, damper definition and contact definition are same as the two-link rigid model. Mass assigned to all parts of deployment mechanism is also same as in two-link rigid model. Primary link and secondary link are made flexible, other parts are kept rigid. Important thing is that the flexible model will introduce the deformation of the parts that form the mechanism. Actual two link flexible model before deployment after deployment (after simulation) is as shown in Figure 14.

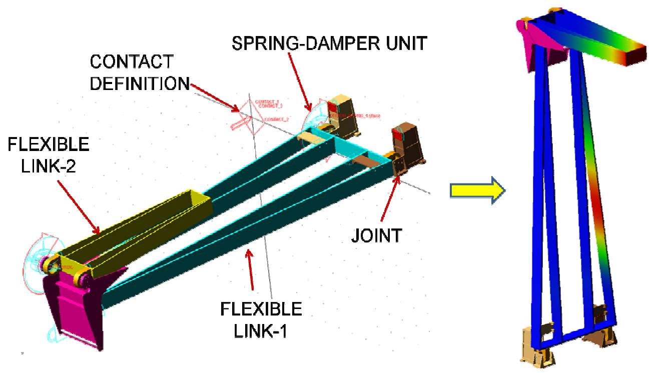

Figure 14: Two link Flexible Model in MSC ADAMS.

5.1 Generation of Flexible Bodies

The flexible parts are generated using the NASTRAN – ADAMS interface of NASTRAN. All the information (model stiffness, mass and loads matrixes, nodes location, mass invariants) are stored in one single file for each flexible body created, a Modal Neutral File (MNF). CREO Elements Pro-E model of primary link is converted into step file. Step file from Creo is then imported in PATRAN where its modal analysis is done using NASTRAN solver. After modal analysis results are saved as a MNF file with NASTRAN-MSC ADAMS interface.

In MSC ADAMS, there is provision to convert rigid body to flexible bodies using MNF file. So MNF file is imported and it precisely aligned with the existing rigid body which is going to be flexible. Then same procedure is followed for secondary link.

5.2 Deployment Mechanism Simulations in MSC ADAMS before and after Damping for Two Link Flexible Model

Estimated value of torsion spring stiffness and damping coefficient were defined at joint-1 and joint-2. Simulation study is carried for two link rigid model for 20 seconds. Simulation study was done before and after damping. Measures are defined at joint-1 to measure joint angle-1, at joint-2 to measure joint angle-2 and C. M. angular acceleration of primary link. Results are given below:

Joint angle-1 Vs time graph for before and after damping is shown in Figure 15. From this graph, it is observed that link-1 achieve its final position i.e. 90 deg in 6.8 seconds before damping and 90 deg in 8.4 seconds after damping.

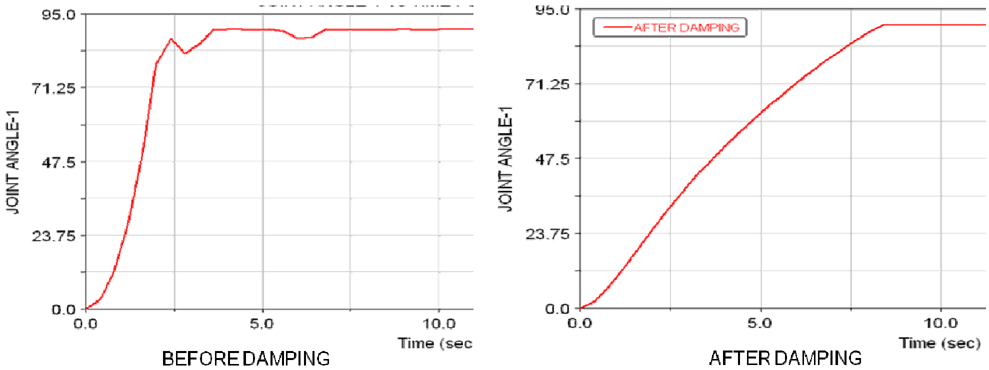

Figure 15: Joint Angle-1 Vs Time (Before and after Damping).

Joint angle-2 Vs time graph for before and after damping is shown in Figure 16. From this graph, it is observed that link-1 achieve its final position i.e. 270 deg in 6.4 seconds before damping and 270 deg in 10 seconds after damping.

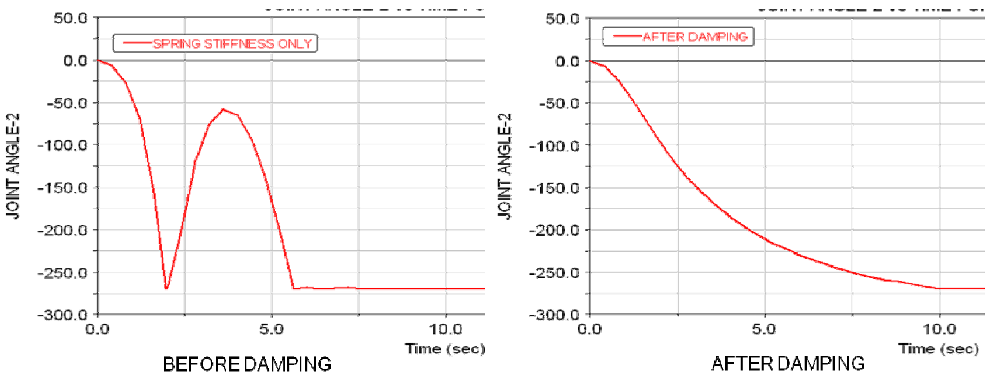

Figure 16: Joint Angle-2 Vs Time (Before and after Damping).

Angular acceleration Vs time graph for before and after damping is shown in Figure 17. From this graph, it is observed that angular acceleration is 3427.81 deg/sec^2 before damping and 54.433 deg/sec^2 after damping.

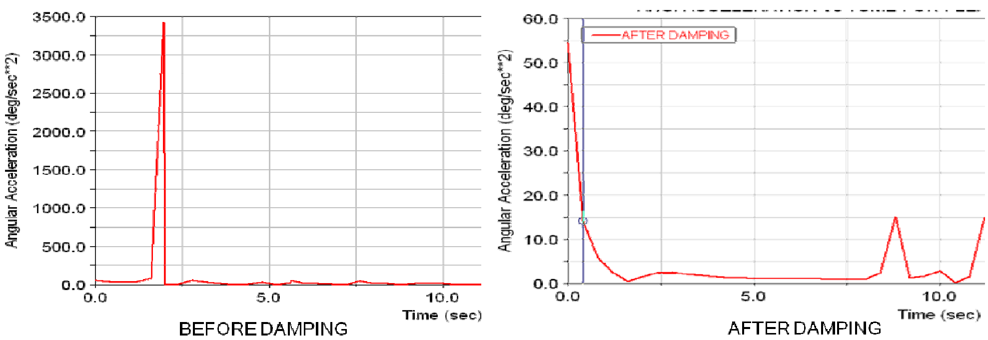

Figure 17: Angular Acceleration Vs Time (Before and after Damping).

6. CONCLUSIONS

- Dynamics of single link and two link model is done. Results comparison is done between mathematical model and MSC ADAMS model. Results are closely matching.
- Deployment dynamics of deployment mechanism for space telescope for rigid link and flexible link model is carried out using MSC ADAMS tool for before and after damping condition to determine deployment time, joint angle for link-1 and link-2 and angular acceleration.
- Desired value of stiffness of spring for complete deployment and damping rate for slow deployment to avoid impact at the end of deployment is estimated.

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